Radiative Transfer in Seagrass Canopies

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LONG-TERM GOALS

The overall objective of this study is to develop models of radiative transfer for optically shallow waters with benthic substrates colonized by submerged plant canopies (seagrasses and seaweeds). Such models will enable the quantitative prediction of upward spectral radiation from vegetated seabeds, thereby permitting (i) the use of optical remote sensing to retrieve bathymetry, (ii) the search for submerged objects of anthropogenic origin and (iii) the mapping of submarine resource distribution and abundance in coastal waters. These models will also have important applications for predicting irradiance levels within SAV canopies, a task necessary for accurate determination of light requirements and photosynthetic productivity of these ecologically important, but increasingly vulnerable coastal resources.

SCIENTIFIC OBJECTIVES

The objectives of this study are to

- Develop radiative transfer models of seagrass and seaweed canopies *in situ* that include canopy architecture (e.g., layers created by multi-species communities), height above the bottom, impacts of water motion and bottom reflectance from the canopy/substrate complex back into the water column.

- Use the resulting models of bottom reflectance to develop hyperspectral remote sensing algorithms of SAV composition and abundance and depth distribution.

- Evaluate the utility of the remote sensing algorithms to retrieve bottom reflectances in both extremely clear Type I tropical waters and in more turbid Type II waters characteristic of temperate coastal and estuarine environments.

APPROACH

The work involves development of mathematical descriptions of canopy architecture (plant density & vertical biomass distribution), reflected upwelling radiance, and light absorption and photosynthesis within submerged plant canopies from direct field observations and laboratory measurements. A system of coupled equations generated from these measurements will be solved for specific scenarios of canopy structure and water column optical properties to evaluate the effect of spectral quality and flux density of the downwelling irradiance on benthic spectral radiance and whole canopy productivity. Radiative transfer modeling within the canopy began with the simple model first proposed by (Monsi & Saeki 1953) which provides an excellent first-order description of radiation interception within closed (horizontally homogeneous) canopies, and is being extended to include the effects of leaf

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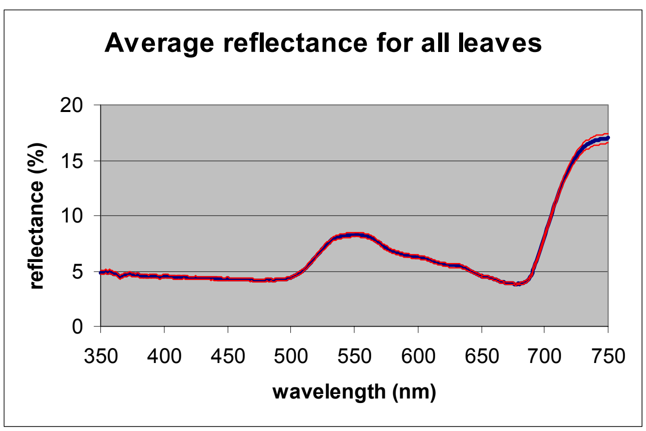
orientation and plant shape using elliptical models and more open architectures using the approach pioneered by (Norman & Welles 1983) for terrestrial plant systems. Model predictions of benthic reflectance and water-leaving radiance are tested against *in situ* measurements to evaluate the degree of agreement between theory and observation. A photosynthesis model based on spectral light absorption is being used to explore the effects of a range of water columns with different inherent optical properties and canopy architectures on photosynthesis, whole plant carbon balance, shoot density and depth distribution.

WORK COMPLETED

In the first year, canopy architecture of the eelgrass meadow growing at Del Monte Beach, Monterey, California, was characterized and a preliminary model of vertical canopy architecture was developed and expanded in Year 2 to include the effect of flow on canopy architecture and spectral distribution of irradiance within the canopy at both Del Monte Beach and at Lee Stocking Island, Bahamas. Year 3 focused on inherent optical properties of individual submerged plants for input into the canopy model, measurement of remote sensing reflectance over submerged plant canopies using a hyperspectral tethered spectroradiometer buoy (HTSRB) and development of a remote sensing algorithm for determining seagrass density at both Del Monte Beach and Lee Stocking Island.

RESULTS

Seagrass leaf IOPs measured during years 1-3 have been completely processed and categorized into basic optical classes. All clean leaves fall into a single optical class in terms of reflectance (Fig. 1). There are, however, two leaf classes for absorptance, based on leaf age (Fig 1). The impact of epiphyte loads on leaf IOPs will receive greater attention in Year 4, and we anticipate that it will create more leaf optical classes for the model.



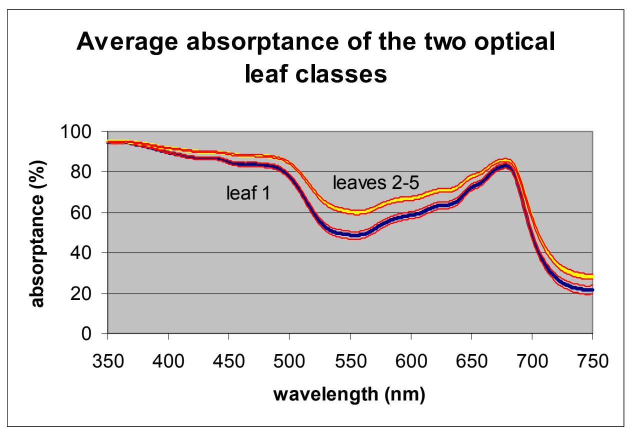


Figure 1. Reflectance and absorptance properties of clean seagrass leaves. Blue lines are the mean of over 200 individual leaf measurements, red lines represent 95% confidence limits of the mean.

Seagrass canopy architecture is a function of total standing leaf area (one sided) per unit area of bottom, the vertical distribution of that biomass above the bottom boundary and the orientation of the leaves with respect to incoming irradiance and viewing angle of the observing instrument. The resulting leaf area projected toward the remote sensing instrument (LAP) can be calculated as:

$$LAP = LAI \bullet \sin(\beta - \theta)$$

where β represents the bending angle of the canopy and θ is the viewing angle of the instrument. The bending angle (β) can be modeled as an exponential function of current velocity (Fonseca et al. 1982,

Koch & Gust 1999). This model provided a good fit to direct observations of bending angle we made in a seagrass bed at Lee Stocking Island during May 1999, allowing us to calculate the leaf area projected in any upward angle as a function of tidal current velocity (Fig. 2).

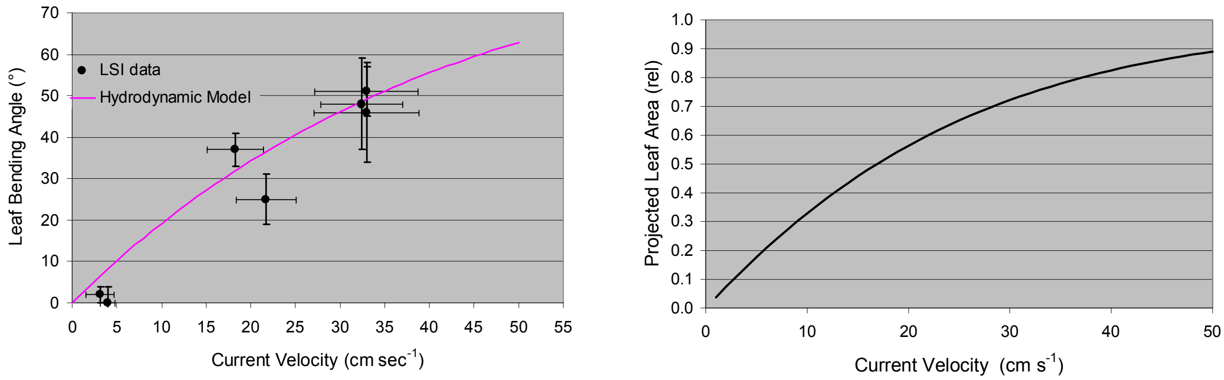


Figure 2. Right Panel: Relationship between free-stream current velocity and leaf bending angle as predicted by a hydrodynamic model based on (Fonseca et al. 1982, Koch & Gust 1999) (magenta line) and measurements obtained at Lee Stocking Island (filled circles). Error bars represent 1 s.d. of the mean. LSI data were collected in May 1999. Left panel: Vertically projected relative leaf area calculated from the bending angles produced by current velocity.

Remotely-sensed observations of percent cover are essentially equivalent to projected leaf area and therefore may be converted into potentially useful estimates of leaf area index and shoot density.

A remote sensing algorithm was developed by creating a range of bottom reflectances (R_b) from pure seagrass to pure sand. The sand spectrum was provided by P. Reid and E. Louchard (RSMAS) from their CoBOP studies of sediment reflectance at Lee Stocking Island. The resulting range of reflectances were used as bottom reflecting boundaries in HydroLight runs designed to calculate the remotely sensed reflectance (R_{rs}) for a clear water column of 5 m depth, typical of conditions at Lee Stocking Island (Fig. 3). Although filtering effects of the water column altered the shape of R_{rs} relative to R_b, strong differences remained with regard to absolute amplitude as well as shape of R_{rs} for the different bottom types created by mixing pure seagrass and pure sand.

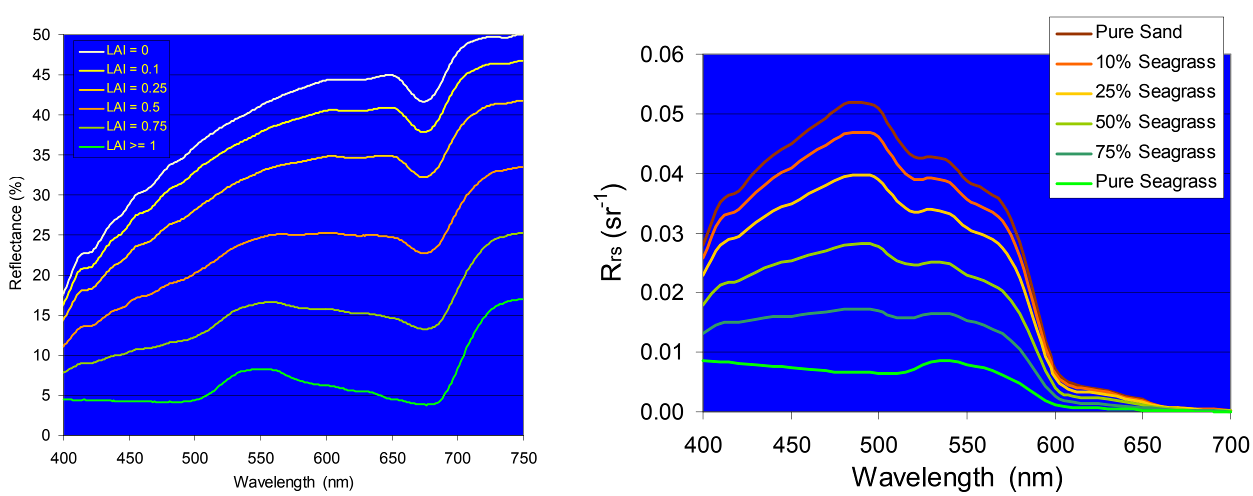


Figure 3. Left Panel: Bottom reflectance spectra ranging from pure seagrass to pure sand used for inputs to HyrdoLight. Right Panel: Resulting remote sensing reflectance spectra predicted by Hydrolight for a 5 m water column.

Fourth derivative analysis of the Hydrolight-generated R_{rs} spectra revealed several wavelength bands whose amplitudes changed in direct proportion to the fraction of seagrass present in the R_b spectrum (Fig 4).

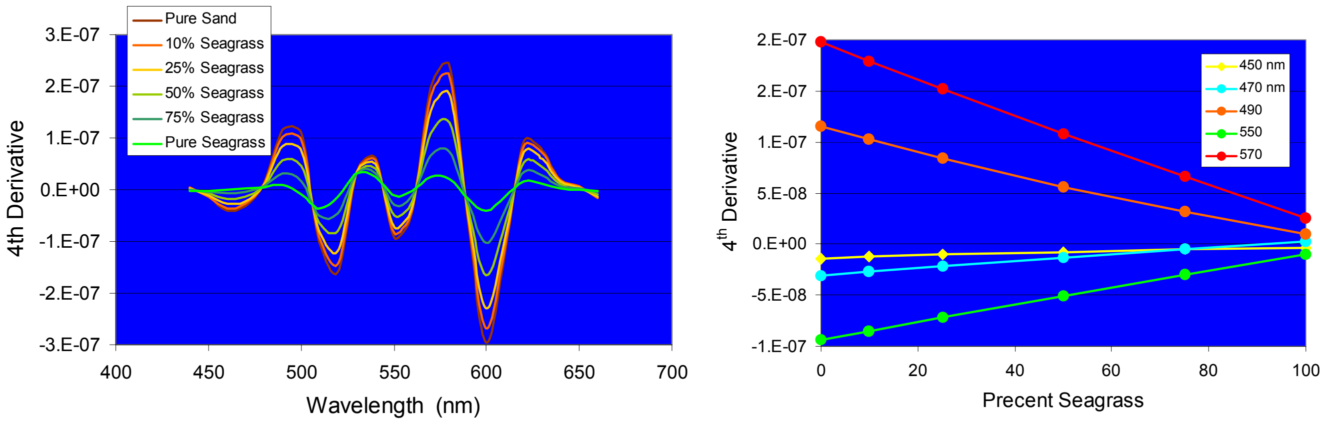


Figure 4. Left Panel: 4^{th} derivative amplitudes of Rr_s shown in Fig. 3. Right Panel: 4^{th} derivative amplitudes at selected wavelengths plotted as a function of % seagrass present in the R_b spectrum used for each Hydrolight run.

Regression analysis (Table 1) revealed that percent seagrass cover could be retrieved from the 4^{th} derivative amplitudes using a simple polynomial regression :

$$\%Seagrass = C2\cdot\left(\frac{d^4R_{rs}(\lambda)}{d(\lambda)^4}\right)^2 + C1\cdot\frac{d^4R_{rs}(\lambda)}{d(\lambda)^4} + b$$

Table 1. Regression coefficients predicting % seagrass from 4^{th} derivative of R_{rs}

Wavelength	C_2	C_1	b	r^2
450	3.73E+17	1.57E+10	147.85	0.9995
470	1.61E+16	3.48E+09	92.62	0.999988
490	2.17E+15	-1.21E+09	111.05	0.999959
550	8.73E+14	1.29E+09	113.60	1
570	2.62E+14	-6.37E+08	115.76	1

This simple algorithm was tested over a HTSRB transect through Adderly Cut near Lee Stocking Island (Fig 5). The transect crossed bathymetries ranging from 2 to 8 m. Seagrass percent cover was estimated using this algorithm and R_{rs} spectra obtained from the HTSRB at three localities along the transect corresponding to dense seagrass, sparse seagrass and pure sand. Percent Seagrass cover was estimated to be 96 ± 11 at the dense site, 87 ± 5 at the "sparse" site and 14 ± 13 at the site identified as 'pure sand". In addition to differences in 4^{th} derivative amplitude, there were spectral differences in peak locations that are probably attributable to differences in depth among the sites. These depth-dependent effects probably explain the estimated 14% seagrass cover at the "pure sand" site. In the next year, we will begin extensive sea-truth evaluation of this algorithm and include a component to include depth effects on the algorithm.

IMPACT/APPLICATIONS

This study is providing critical data sets and models required to understand the dynamics of radiative transfer in optically shallow waters characterized by a variety of benthic substrates, including submerged aquatic vegetation. Such information is critical for the evaluation of remote sensing

algorithms designed for shallow water applications including the search for and identification of anthropogenic objects and environmental resource monitoring and mapping applications.

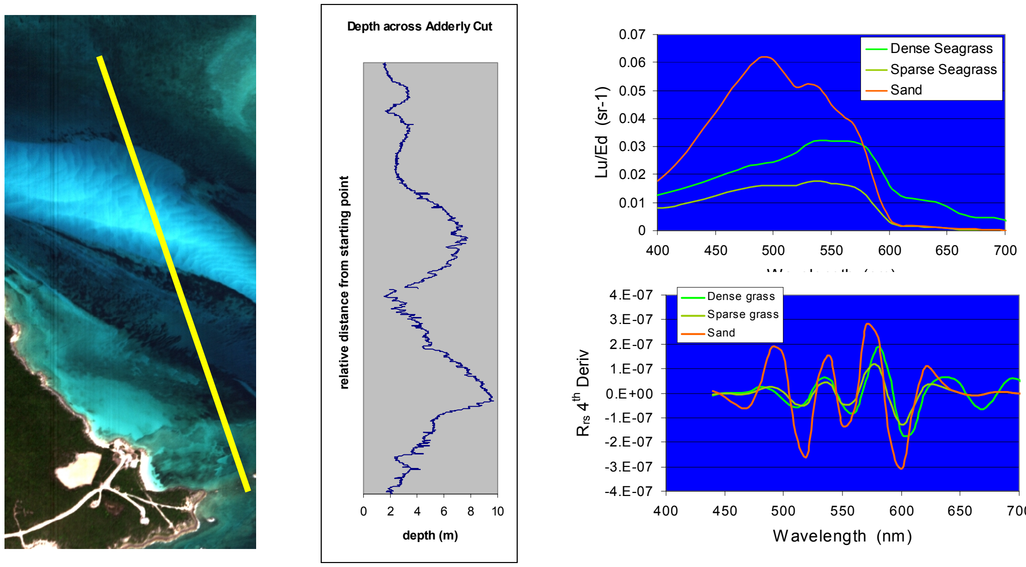


Figure 5. Left panel: PHILLS image of Adderly Cut with HTSRB transect indicated by the yellow line. Dark areas are vegetated by seagrass, lightest blue area is pure sand. Lee Stocking Island appears in the lower left corner. Left-center panel: Depth profile of the HTSRB transect recorded across Adderly Cut. Top-right panel: Spectra of L_u/E_d recorded by the HTSRB over the three areas analyzed by the seagrass algorithm. Bottom-right: 4^{th} derivatives of the L_u/E_d spectra.

TRANSITIONS

All data collected are being prepared for transfer to the CoBOP data base for archival and use by other scientists. We have already exchanged data sets with M. Kappus, W. Philpot, R. Maffione, P. Reid, F. Dobbs as part of various CoBOP-related collaborations. This work has attracted considerable attention from seagrass management agencies and other scientists interested in coastal water quality and resource monitoring. David R. Young of the U.S. E.P.A. office in Newport OR has expressed interest in using our HTSRB algorithm to map seagrass distributions in Newport Bay, OR, and we plan to assist him in testing the utility of this algorithm in FY2000.

RELATED PROJECTS

The efforts described above are being performed in collaboration with other CoBOP participants to produce measurements of light field characteristics within and above seagrass meadows and to develop more realistic light field models for shallow benthic canopies. The observed data will be compared to model calculations as part of the closure experiments fundamental to the CoBOP program. These data are also being made available to researchers in the HYCODE Program for their development of remote sensing algorithms. Finally, CoBOP supported collaborations with Dr. D Burdige on CDOM production and carbonate sediment dissolution in seagrass meadows is proving useful to a new project funded by the Japanese government investigating environmental remediation and CO_2 sequestration techniques in shallow coastal waters.

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